

## Why the OZI rule is so strongly violated in $J/\Psi$ decays?

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The new  $f_0(1790)$  meson recently observed by BES collaboration in  $J/\Psi$ -decay, is seen only in the OZI-forbidden channel. It is shown that chiral symmetry restoration in excited hadrons implies a new selection rule of dynamical origin that forbids some of the OZI-favoured mechanisms of decays. Hence decays into channels that are suppressed by OZI can become dominant.

A recent remarkable result by BES collaboration on  $J/\Psi$  decay into  $\phi\pi^+\pi^-$  and  $\phi K^+K^-$  has established a new scalar meson,  $f_0(1790)$ , with  $M = 1790^{+40}_{-30}$  MeV and  $\Gamma = 270^{+60}_{-30}$  MeV with the dominant  $\bar{n}n = \frac{\bar{u}u + \bar{d}d}{\sqrt{2}}$  valence quark content [ 1]. This state is observed as a  $15\sigma$  peak in  $\pi^+\pi^-$  while its decay into  $KK$  is strongly suppressed. Actually this state was seen earlier in the London-S.Petersburg partial wave analysis of  $\bar{p}p$  at LEAR at  $1770 \pm 12$  MeV [ 2, 3] and some other reactions [ 3].<sup>2</sup> It was also claimed in those publications that this state must be a  $\bar{n}n$  state and should not be confused with the nearby  $f_0(1710)$ , which is predominantly a  $\bar{s}s$  state. This claim of the London-S.Petersburg group has been indeed confirmed by BES since  $f_0(1710)$  is clearly seen in  $J/\Psi \rightarrow \omega(K^+K^-)$  and  $J/\Psi \rightarrow \phi(K^+K^-)$ , while  $f_0(1790)$  is not visible there. There is definite peak in  $J/\Psi \rightarrow \phi(\pi^+\pi^-)$  for  $f_0(1790) \rightarrow \pi^+\pi^-$  while the signal for  $f_0(1710)$  is very strongly suppressed.

This  $f_0(1790)$  state is very interesting as it rules out many existing scenarios for the light mesons. Indeed, there is a well established state with the predominantly  $\bar{n}n$  content  $f_0(1370)$  and the new discovered  $f_0(1790)$  must be its radial excitation. In between there are well established  $f_0(1500)$  and  $f_0(1710)$  which are predominantly glueball and  $\bar{s}s$  states, respectively, with some mixing [ 4]. Actually there are further radial excitations of  $\bar{n}n$   $f_0$  mesons:  $f_0(2040)$  and  $f_0(2337)$  which are seen in a few different channels in  $\bar{p}p$  [ 5, 3].

A very intriguing observation of BES is that the  $f_0(1790)$  state is seen only in the OZI-forbidden channel  $J/\Psi \rightarrow \phi f_0(1790) \rightarrow \phi\pi^+\pi^-$ . Indeed, the OZI rule would require that the  $\bar{n}n$  state should be accompanied by  $\omega$ , but not by  $\phi$ , see Fig. 1, because  $\phi$  has a well established  $\bar{s}s$  content. However,  $f_0(1790)$  is not seen in  $J/\Psi \rightarrow \omega(\pi^+\pi^-)$  and is seen only in  $J/\Psi \rightarrow \phi(\pi^+\pi^-)$ , see Fig. 2. Then there arise two independent questions. (i) Why the OZI mechanism does not work? (ii) Which specific mechanism is behind the Fig. 2 and why

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<sup>2</sup>The spin 0 assignment of this state is preferred over spin 2 in the BES publication, while such an assignment is conclusive in  $\bar{p}p$  [ 2, 3].

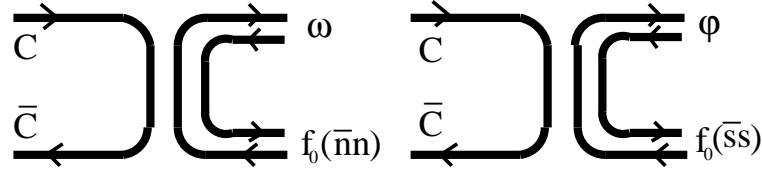


Figure 1. The OZI-favoured decays into two mesons.

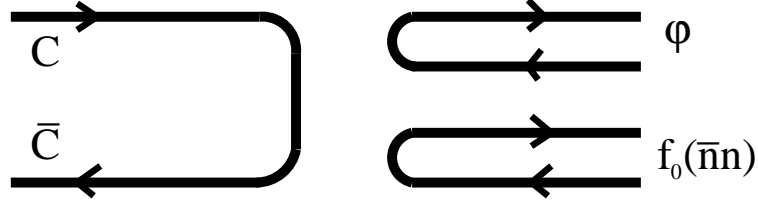


Figure 2. The OZI-forbidden decay.

then the OZI forbidden doubly disconnected mechanism of decay  $J/\Psi \rightarrow \omega f_0(\bar{n}n)$  (with the  $\phi$ -meson on Fig. 2 to be substituted by the  $\omega$ -meson) is relatively suppressed?

A purpose of this note is to demonstrate that restoration of chiral symmetry in excited hadrons [ 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16] would imply a new dynamical selection rule that forbids  $f_0(1790)$  to be accompanied by  $\omega$  meson in  $J/\Psi$  decay via the OZI-allowed mechanism. Then this decay via the OZI-forbidden diagram(s) like of Fig. 2 can be indeed dominant. We do not attempt, however, to answer the interesting question (ii). Clearly this answer will necessarily invoke microscopical models for decay, which is beyond the scope of this paper. The suppression of the OZI-favoured mechanism by chiral symmetry is a general claim and equally applies to other possible decays of the heavy quarkonium into two mesons with one of the mesons being in the chirally restored regime.

Restoration of the chiral symmetry in excited hadrons requires that the highly excited hadrons in the  $u, d$  sector fall into representations of  $SU(2)_L \times SU(2)_R$  or  $U(1)_A$  group. There are empirical evidences for this phenomenon both in excited baryons and mesons [ 6, 7, 8, 9, 10, 11], for overview see Ref. [ 15]. In particular, a spectrum of excited  $\pi$  and  $\bar{n}n f_0$  mesons represents one of the clearest manifestations from this phenomenon [ 8], see Fig. 3. Indeed, if chiral symmetry was not broken in the QCD vacuum, then all  $\pi$  and  $\bar{n}n f_0$  mesons would be systematically degenerate and fall into  $(1/2, 1/2)$  representations of  $SU(2)_L \times SU(2)_R$ . Spontaneous breaking of chiral symmetry in the vacuum removes this degeneracy and the ground state pion turns into Goldstone mode with zero mass. However, the quark condensates of the vacuum become progressively irrelevant in the radially excited hadrons where the valence quarks decouple from the quark condensates and the chiral symmetry gets approximately restored in the given hadronic state and in the spectrum [ 7, 14]. Fundamentally this happens because quantum fluc-

tuations of the quark fields, which are the origin of spontaneous breaking of chiral symmetry, get suppressed in excited hadrons and a semiclassical description becomes adequate [ 11]. In particular, an approximate degeneracy within the  $\pi(1800) - f_0(1790)$  chiral pair demonstrates how insignificant are the remaining effects of chiral symmetry breaking in the vacuum for the  $n = 3$  state where  $n$  is the radial quantum number.

While for the large  $N_c$  limit the effective restoration of chiral symmetry in excited mesons has been proven [ 7, 14], this phenomenon should be still considered as a conjecture in the  $N_c = 3$  world until the missing states in the chiral multiplets will have been found. One can try to argue that the approximate parity doublets seen in the spectrum are accidental and the states of opposite parity actually belong to close shells with alternating parity in the spirit of the naive constituent quark model. However, the assumptions of the constituent quark model, if valid for the  $N_c = 3$  world, must be equally valid for the large  $N_c$  mesons. In the latter case the chiral restoration does occur and hence the naive constituent quark picture of excited mesons is ruled out, at least in the large  $N_c$  limit.

Now comes the key point. Once the chiral symmetry is restored, then the valence quark wave function is fixed in terms of the right- and left-handed quark components:

$$f_0 : \frac{\bar{R}L + \bar{L}R}{\sqrt{2}},$$

$$\pi : \frac{\bar{R}\tau L - \bar{L}\tau R}{\sqrt{2}},$$

where  $\tau$  are isospin Pauli matrices and  $L$  is a column consisting of the left-handed  $u$  and  $d$  quarks, while  $R$  is a column consisting of the right-handed  $u$  and  $d$  quarks. Given almost perfect degeneracy of  $f_0(1790)$  and  $\pi(1800)$  states one naturally assumes that an admixture of the components violating chiral symmetry in  $f_0(1790)$  is very small. Then the OZI-favoured decay mechanism via two or three perturbative gluons (depending on the C-parity of the decaying heavy quarkonium), see Fig. 4, would require that the same right-left structure should persist for the other quark-antiquark pair that is a source for the accompanied meson. This is because the quark-gluon vertex conserves chirality for massless quarks. However, the  $\frac{\bar{R}L + \bar{L}R}{\sqrt{2}}$  quark pair has positive parity and cannot be a source (interpolating field) for the  $\omega$  meson, which is a vector particle. Then one concludes that the OZI-favoured decay mechanism of  $J/\Psi \rightarrow \omega f_0(1790)$  is forbidden by chiral symmetry. Clearly, there are no chiral symmetry restrictions for the OZI-forbidden channel of Fig. 2.

It is rather obvious that this and similar chiral symmetry selection rules of dynamical origin are rather general and can (and should) be observed in many other cases. For example, the same rule is directly relevant to  $f_0(1370)$ , that is also observed in the OZI-forbidden decay,  $J/\Psi \rightarrow \phi f_0(1370)$ , and is not seen in the  $J/\Psi \rightarrow \omega f_0(1370)$ , which is another claim of BES. Indeed, as is seen from the Fig. 3,  $\pi(1300 \pm 100) - f_0(1370^{+130}_{-170})$  is the lowest-lying approximate chiral pair seen in the  $\pi$ - $f_0$  spectra.

In general, in any two-meson decay of the heavy quarkonium and once one of the mesons is in the chirally restored regime the chiral symmetry does not support generically the OZI decay mechanism<sup>3</sup> and hence the strong violations of the OZI rule should be expected. This can be studied at BES, CLEO and other similar facilities.

<sup>3</sup>Except for the cases when both mesons have equal quantum numbers.

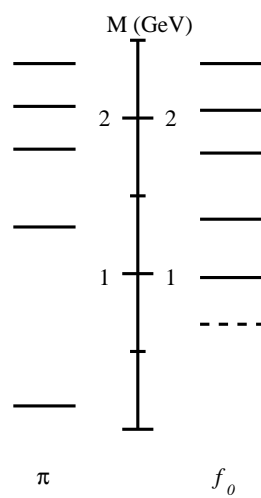


Figure 3. Pion and  $n\bar{n}$   $f_0$  spectra.

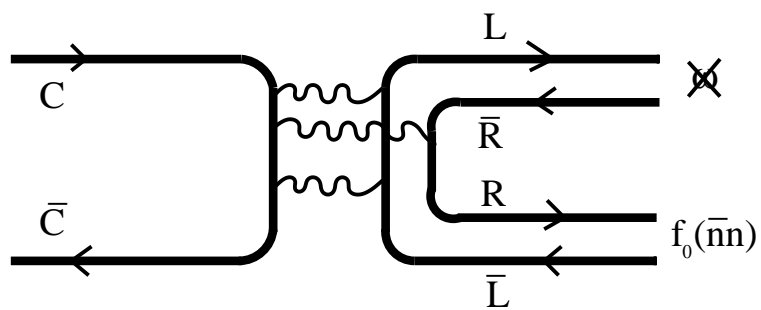


Figure 4. The OZI-favoured decay which is forbidden by chiral symmetry.

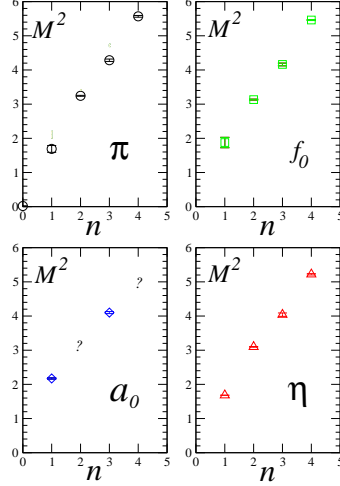


Figure 5. Radial Regge trajectories for the four successive high-lying  $J=0$   $\pi$ ,  $a_0$ ,  $\bar{n}n$   $f_0$  and  $\bar{n}n$   $\eta$  mesons. For details see Ref. [ 8]

In particular, this selection rule should be taken into account once a search of the two missing  $a_0$ -mesons, see Fig. 5, as well as a confirmation of the  $a_0$ -meson around 2 GeV, are undertaken. The existence of these states follows from the existence of their chiral partners [ 8]. Namely, their  $SU(2)_L \times SU(2)_R$  partners are the  $\bar{n}n$   $\eta$ -mesons, while the  $U(1)_A$  partners are the  $\pi$ -mesons. Hence masses of the high-lying  $a_0$ -mesons can be approximately estimated from the observed  $\pi$ - and  $\eta$ -mesons. A search of the missing  $a_0$ -mesons can be performed e.g. in  $\chi_{c0} \rightarrow a_0(980) + a_0(?)$ . This decay is not chirally suppressed. On the contrary, charmonium decay into two mesons, with one of them being  $\pi$  or  $\rho$  and the second one being a high-lying  $a_0$ -meson, should be chirally suppressed.

As a conclusion, we have demonstrated a simple and clear selection rule of dynamical origin, dictated by chiral symmetry, which forbids some OZI-allowed decay mechanism. Hence some of the states, where chiral symmetry is approximately restored, can be observed in the OZI-forbidden channels, where there are no chiral symmetry constraints. It is an important feature that this explanation is coherent with the previously discussed restoration of chiral symmetry in excited hadrons.

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16. This is a subject of many talks at the ECT Workshop "Highly Excited Hadrons", ECT, Trento, July 4-9, 2005; slides are available at <http://www.ect.it>